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# AIR TESTING OF AN SSME TURBOPUMP USING RAPID PROTOTYPING TECHNOLOGY

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## Abstract

An air test program was performed to evaluate a redesigned diffuser for use in the Space Shuttle Main Engine (SSME) Large Throat Main Combustion Chamber (LTMCC). Rapid prototyping was used to fabricate many different diffuser design concepts to allow more testing than was achievable using conventional manufacturing. The rapid prototyping process proved capable of producing the consistent parts needed to evaluate small performance differences among multiple design geometries. Understanding the lessons learned at Rocketdyne from using rapid prototyping in air testing may aid others in the design verification process.

## Background

During a shuttle launch, the engines are designed to throttle between 65% and 104% power levels. Current SSME engines are limited to 67% of the design power level due to a bi-stability of the High Pressure Oxidizer Turbopump (HPOTP) preburner pump. The bi-stability has proven to be a flow-related phenomenom which is primarily attributed to the diffuser/volute design. The LTMCC SSME-variant reduces the preburner pump flow rate at all power levels, aggravating the bi-stability condition. Based on previous operating experience, the LTMCC engines may be restricted to operation above 70% power level.

To ensure stable operation at 65% power level with the LTMCC engines required redesigning the diffuser/volute to move the stall point out of the necessary operating range. The contraints on the new design required minimal effect on the pump's head-flow characteristic. The design effort was concentrated on modifying diffuser blade geometry, without changing the volute shape.

Rapid prototyping was chosen as the manufacturing process because of the promise of minimum fabrication time, and consequently shorter test turnaround time, afforded by the technology. The hardware was fabricated in Rocketdyne's Rapid Prototyping Laboratory with a DTM Sinterstation 2000 machine, which uses selective laser sintering.

## Test Rig Description

The testing was performed in Rocketdyne's Engineering Development Laboratory Pump Test Facility in Canoga Park, California. Actual hardware from a preburner pump was modified to fit into an existing air test rig. The rig is capable of variable speed operation between 4000 and 14500 rpm. The bearing package was specially designed to be stiff enough to support cantilevered rotating components without having any air leakage through the unit. Figure 1 is a cross-section of the test rig.

A production diffuser/volute was modified to remove the diffuser vanes, allowing insertion of the rapid prototyped polycarbonate diffuser rings for testing. Figure 2 is a photograph of a polycarbonate diffuser ring installed in the tester. Instrumentation was added to measure inlet, impeller discharge, diffuser discharge, and pump discharge pressures. Orifices were placed in the inlet and discharge pipes to measure flow rate continuity, verifying a leak-free system. A hydraulic valve was placed at the system discharge to allow precise control of flow rate.

## Benefits of Rapid Prototyping

The turnaround time for a rapid prototype part was no more than three days from completion of the model to delivery of a part for testing. This delivery rate is conducive to frequent testing of multiple parts in a compressed schedule. In all, 9 parts were fabricated during the project, with a total of 77 distinct tests completed in 46 test days. Such a comprehensive test schedule would not have been accomplished using conventional machining. Besides eliminating the need for various machining setups to fabricate the diffuser vanes was the ability to incorporate static pressure instrumentation holes directly into the fabrication process. In this case, 0.090-inch diameter holes were built into the part to measure the circumferential pressure distribution at the diffuser discharge. An added benefit was the ability to integrate recently acquired test data "on-the-fly" into the next design iteration for the diffuser without significantly affecting schedule. This is particularly important when fine-tuning a design for optimal performance.

## Considerations

### Porosity

Porosity is a key concern when considering parts made using laser sintering of polycarbonate powder. Because of the nature of the process, voids form between layers to create a part which is approximately 80% dense. A pressure test of a part showed leakage at pressures as low as 0.12 psig. Two methods were evaluated for eliminating the effect of porosity: hot wax dipping and epoxy filling. With epoxy filling, liquid epoxy is applied to all exposed surfaces, allowing capillary action to pull the epoxy into the part. After a set cure time, the part is essentially non-porous. Since this is a manual operation, consistency of the parts is less reliable. In hot wax filling, the polycarbonate part is dipped in a hot wax bath to absorb wax and fill the pores. The part is then removed from the bath, placed in a text fixture, and spun to approximately 70 rpm to shed wax which accumulated on the surface. The consistency of the surface finish of the part can be controlled by adjusting the time in the bath and spin time. Parts which are treated using either technique have been pressure tested to 1 psig without leakage.

### Surface Finish

Surface finish must also be considered when rapid prototyped parts are used to simulate performance of a smooth finished metal part. The parts used in the SSME project had surface finishes on the order of 800 to 900 microinch, whereas the production diffuser finish was 125 microinch. This difference manifested itself directly in a comparison of the head-flow performance results of the production metal diffuser and its polycarbonate counterpart as shown in Figure 3. Above the stall point, the metal diffuser had higher head. Because of the sharper stall behavior of the metal diffuser, its head was lower than the polycarbonate diffuser below the stall point. The lower surface finish of the polycarbonate parts resulted in higher losses and lower head. Analytical models show the relative differences to be consistent with expectations based on the surface finish variation. Test samples using polycarbonate indicate a consistent surface finish of 800 microinch is achievable. With an epoxy coat, the surface finish decreases to 300 microinch. With wax, the achievable surface finish is 315 microinch.

The difference in the stall steepness was thought to be caused by a combination of surface roughness and leading edge sharpness. Figure 4 presents the results from two tests using a diffuser with the as-fabricated leading edge shape and the same diffuser with the leading edges sharpened. The sharpened leading edges caused a noticeable steepening of the stall curve. The steepness of the diffuser stall performance was also dependent on the surface finish. Figure 5 shows the head-flow performance of diffuser Redesign #2 tested after applications of one and two coats of epoxy. The first coat of epoxy was sufficient to fill in the pores, yet not build up the surface. The second coat was applied conservatively to add a moderate surface finish improvement. This incremental improvement of surface finish was sufficient to significantly alter the head and stall behavior of the diffuser.

To successfully evaluate the results of air testing with rapid prototyping, the surface finish issue must be addressed. Either the air test results must be corrected to correspond to the desired surface finish, or a baseline must be established to allow relative comparisons of parts. Rocketdyne's design approach was to verify the surface finish effect by testing both the metal and polycarbonate versions of the current diffuser design. As stated earlier, analysis showed surface finish accounted for the difference in head. The selection of the best diffuser design for the LTMCC, however, was based on relative comparisons between the baseline polycarbonate diffuser and subsequent redesign efforts. Using relative comparisons reduced the surface finish concerns and returned the decision making process to the performance merits of the individual designs.

Part to Part Variation

Two different parts were fabricated from the same design geometry to test the part to part variation introduced by the rapid prototyping process. Figure 6 shows a plot of equivalent head vs equivalent flow for the different parts. The data indicates there is good agreement between the parts over the entire flow range. The maximum deviation in head is 1%, while the stall point varies by 0.003. Both of these results are within the experimental test to test variation experienced during the project.

## Conclusions

Rapid prototyping is an appropriate means for air testing turbomachinery design concepts, especially when budget and schedule are restricted. Performance testing has shown rapid prototyped parts can be fabricated with consistent results on tightly toleranced bladed surfaces. Considerations must be given to the shortcomings of the process, primarily porosity and surface finish control, when preparing for a test project. The ideal situation for using rapid prototyping in testing is when relative comparisons are being made between different geometries. By establishing a baseline design and then evaluating relative improvements, Rocketdyne was able to assess the merits of individual designs on performance alone. Using rapid prototyping in air testing allowed Rocketdyne to successfully complete the redesign of the HPOTP preburner pump for use in the LTMCC.

## Acknowledgements

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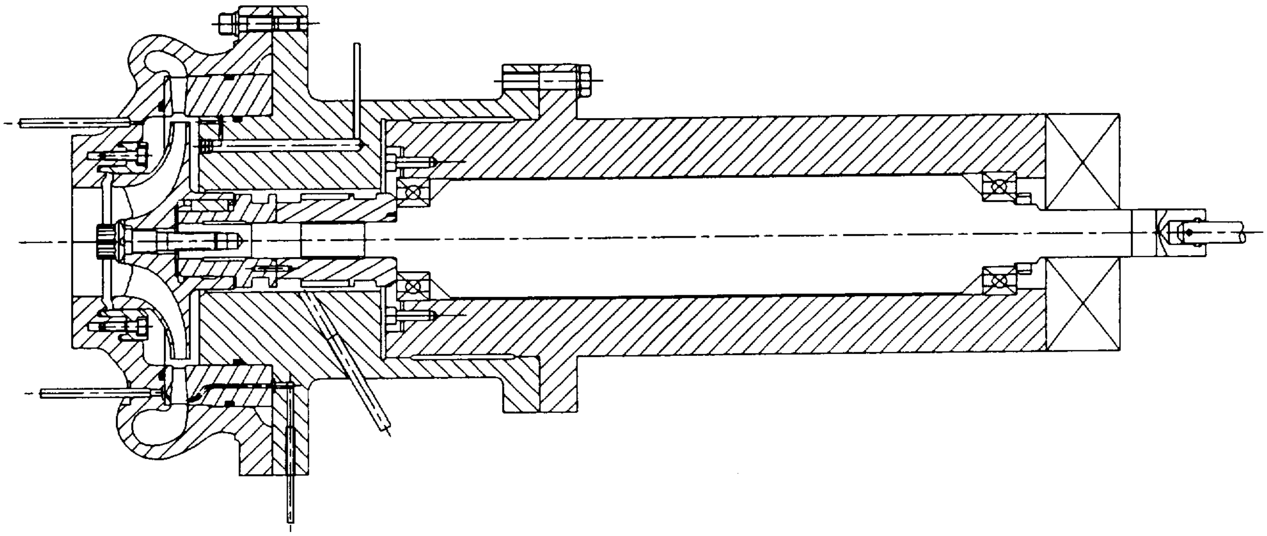

Figure 1. Cross-Section of the SSME Preburner Pump Air Test Rig

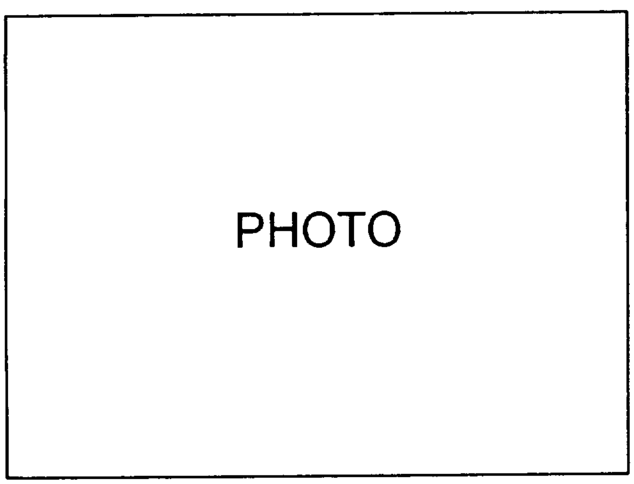


Figure 2. Polycarbonate Diffuser Ring

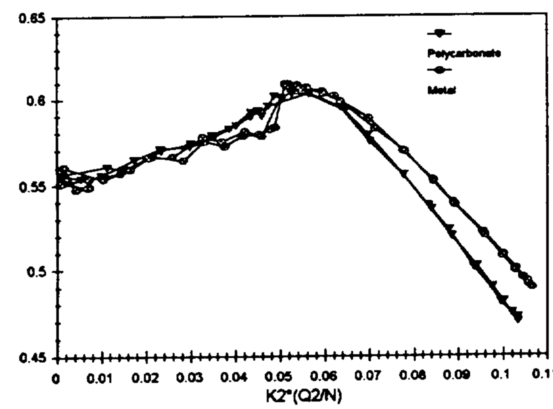


Figure 3. Comparison of Metal to Polycarbonate

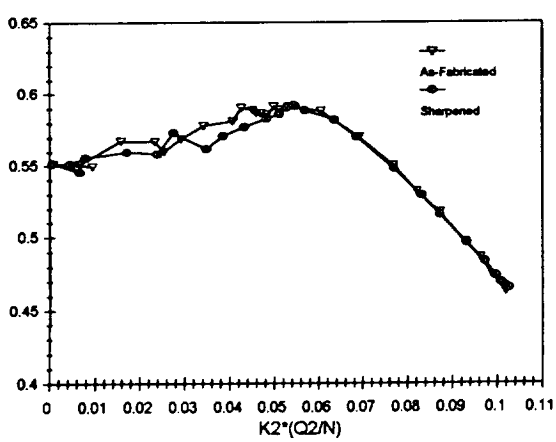


Figure 4. Effect of Blade Sharpness

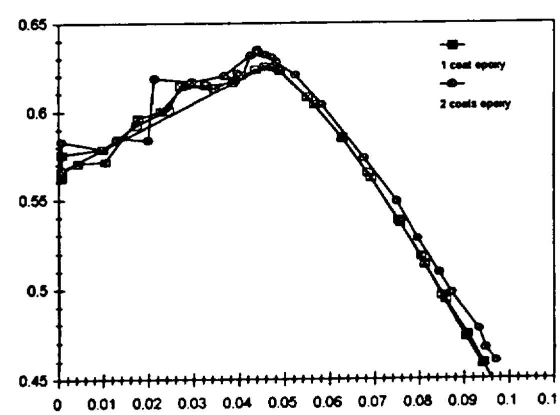


Figure 5. Effect of Surface Finish

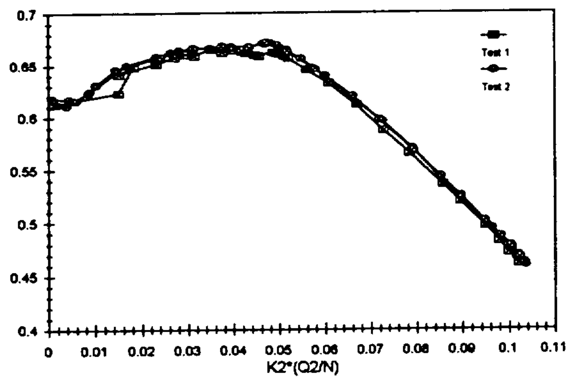


Figure 6. Part to Part Variation